BIO-ACOUSTIC STUDIES OF HIGH INTENSITY AIRCRAFT ENGINE NOISE AT THE NAVAL AIR TEST CENTER AND ABOARD USS CORAL SEA (CVA-43)

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AUDIOMETRIC STUDIES AT

NAVAL AIR TEST CENTER

30 September - 2 October 1953

Preliminary experiments under TED PTR-SI-442, Bio-Acoustic Aspects of High Intensity Aircraft Engine Noise, were conducted 30 September to 2 October 1953 at the Naval Air Test Center, Patuxent River, Maryland. These experiments included measurement of the sound levels around twin jet aircraft with afterburners and exposure of personnel to the noise produced by these aircraft. The hearing of the personnel was evaluated by routine audiometry. This section deals with the audiometric measurement and with the subjective reports of the personnel involved.

Test Method:

Individual audiograms were taken on a Maico H-1 audiometer in an ordinary laboratory room near the flight line. The room was not specially treated and therefore was subject to considerable intermittent noise from flight line operations. Many audiograms, both control and post-exposure, showed irregular fluctuations characteristic of variable masking. The audiometry was performed by a Navy medical technician.

Test Subjects:

Seventeen enlisted Navy personnel, selected at random regardless of rate, were given otologic and audiometric examinations and carefully fitted with either V51-R or old style Mine Safety Appliance earplugs. One subject was eliminated from the group because of active discharge from his ear based on a chronic otitis media. Five subjects had histories of previous otitis media in one or both ears. On examination, except for well healed scars on the tympanic membranes, these ears were essentially normal and the control audiograms were within 10 db of normal. These subjects were retained for the study. All other ears appeared to be normal.

Procedure, First Day:

After preliminary personal exploration of the noise by the consultants the test subjects, all wearing earplugs, were stationed in groups of two to five around test aircraft "A" and exposed to noise levels as indicated in Table I.

TABLE I

Position Bearing	Position Distance	Sound Pressure Level in DB	Number of Subjects
225°	12.5 ft	150*	3
225°	25	146*	5
240°	50	135	3
315°	25	132	2
315°	50	126	2

*Estimated from SPL at 50 ft. distance

The exposures consisted of 21 bursts of noise from the engines running at full power with afterburner. These bursts lasted approximately 15 seconds and were separated by 30 to 45 second intervals during which the engines idled. Post-exposure audiograms were taken during the period 2 to 3 hours after the end of the exposure.

Procedure, Second Day:

The subjects were stationed in groups of three or four between two test aircraft as indicated in Table II. "B" was on the own right of aircraft "A".

TABLE II

Reference	Position Bearing	Distance	Sound Pressure Level in DB	Number of Subjects
Aircraft "A"	135°	12.5 ft	150*	4
Aircraft "B"	225°	12.5 ft	150*	4
Aircraft "B"	225°	50 ft	124	3
Aircraft "A"	135°	50 ft		
Halfway between and abreast of each aircraft			129-133	4

*Estimated SPL

The exposure consisted of ten bursts of noise from aircraft "A" with both afterburners operating and aircraft "B" with one afterburner operating and then eight bursts of noise from aircraft "A" with both afterburners and aircraft "B" at full power without afterburners. Again the bursts lasted approximately 15 seconds and were separated by 30-45 second intervals during which the engines idled. The audiograms were taken during the period 30 to 90 minutes after the end of the exposure.

Results:

Both control and post-exposure audiograms showed irregular variations in threshold which are more characteristic of intermittent masking than of temporary hearing loss induced by noise. In spite of these irregulatities the mode of distribution of all the control threshold readings indicated that the subjects as a group had normal hearing and that the audiometer was properly calibrated with the possible exceptions of the frequencies 5792 cps and 8192 cps which gave hearing losses 5 db too high and 5 db too low respectively.

No individual audiograms, control or post-exposure, showed clear-cut evidence of either permanent or temporary hearing loss in the subjects. Any temporary threshold shifts occurring in subjects who wore earplugs while exposed to this jet noise spectrum would have occurred principally for the frequencies 512 and 1024 cps. Since masking by ambient noise also occurs principally for these and lower frequencies, it is difficult if not impossible to distinguish the two phenomena. Several individual audiograms showed post-exposure shifts of 15 to 25 db which are consistent with either phenomenon. When the averages of all control thresholds are compared to the averages of all post-exposure thresholds, as in Table III, it is clear that the differences are slight (less than 5.3 db) and can as easily be attributed to variations in masking noise from day to day as they can to any hearing loss.

TABLE III

Frequency	A. Average Control Threshold in DB (N-32)	B. Average Post-Exposure Threshold in DB (N-64)	C. Average "Hearing Loss" in DB (B-A)
128	4.7	10.0	5.3
256	4.7	8.3	3.6
512	5.6	9.7	4.1
1024	6.4	9.4	3.0
2048	3.6	8.8	5.2
2896	10.8	6.9	-3.9
4096	3.6	5.3	1.7
5792	8.4	3.7	-4.7
8192	1.3	1.2	-0.1
11584	7.0	5.[illegible]	-1.8

The average thresholds shown in Table III include some that are elevated by the ambient noise. The averages therefore show slight hearing losses, even for the control audiograms. The thresholds for 2048, 2896, 4096 and 5792 cps are less affected by masking than the lower frequencies due to the acoustic characteristics of the earphone cushions. These thresholds were therefore examined separately. Any previously-existing permanent hearing losses should appear for at least two of these frequencies. When the most representative threshold for each frequency was chosesn from the three available audiograms and when the 5 db corrections for 5792 cps and 8192 cps are applied, no individual audiogram showed more than 10 db hearing losses at any two adjacent frequencies. When the five subjects with history of previous ear infections are eliminated, the average audiogram for the remainder becomes remarkably normal. The average "best" audiogram for the group and the average "best" audiograms for the subjects with and without past medical history of ear infection are given in Table IV.

TABLE IV

	2048	2896	4096	5792
Average, All subjects (32 ears)	3.3	1.1	2.5	1.4
Average, No med. history (24 ears)	2.5	-0.2	2.1	0.2
Average, Positive medical history (8 ears)	5.6	5.0	3.8	5.0

Subjective Symptoms and Opinions:

The subjects reported the following sensations, which varied in intensity according to the intensity of sound to which each subject had been exposed.

1. Vibration of soft tissues of nose
2. Slight difficulty breathing
3. Strong vibration of jaw when mouth was open
4. Vibrations, nearly painful, in the sinuses
5. Aching in region of mastoid after the exposure

Only one subject believed that it would not be reasonable to launch the test aircraft from a carrier. This man's attitude, however, even at the time of otologic examination, was sufficiently skeptical and cynical to cause the examiner to make written notation to that effect. This man predicted trouble after a whole day's operation but not from a few isolated launches.

AUDIOMETRIC TESTS AND PSYCHOSOMATIC SURVEY

ABOARD USS CORAL SEA (CVA-43)

26-30 October 1953

GENERAL PLAN

The second phase of the study of the Bio-Acoustic Aspects of High Intensity Aircraft Engine Noise (TED PTR-SI-442) was conducted aboard the USS Coral Sea during the period 26-30 October. The general outline of these tests is as follows.

Preliminary tests of hearing had been obtained by the Senior Medical Officer on 117 members of the flight deck crew of the USS Coral Sea on board ship prior to the present tests. An additional 18 men with pre-exposure audiograms were available from the Naval Air Test Center.

As in the preliminary tests at the Naval Air Station the personnel were divided into groups, in this case of five men each. These groups were stationed in nine predetermined positions near the aircraft in areas normally occupied by personnel during routine launching operations. The engines of two aircraft were operated simultaneously, including afterburners, in a series of cycles representing a launching operation.

Measurements of the sound levels were obtained systematically around a single aircraft, with and without afterburner in operation, and additional measurements were made of the noise at the positions occupied by the personnel while both afterburners were operating simultaneously.

The personnel exposed to the noise all wore ear protective devices of some sort. Several types of helmets that incorporated over-the-ear protection were used. In the areas where preliminary noise measurements and personal exploration by the consultants showed noise levels of 140 db or more insert-type earplugs (V51-R) were worn by all personnel in addition to the helmets.

In order to obtain the maximum information from a restricted series of systematic acoustic exposures the groups of five men in each area were made as similar as possible by selecting them according to the results of the Cornell Medical Index (CMI) Health Questionnaire. The questionnaire was administered the day before the first exposure to noise to the 114 members of the crew of USS Coral Sea who had had preliminary audiograms.

Audiograms were obtained on all exposed personnel during the two hour period immediately following the exposure to noise on each of two days and an additional audiogram was obtained on 29 of them on a later day without exposure to noise.

The Health Questionnaire was repeated after the second exposure and the personnel were also asked to answer another series of questions concerning nonauditory sensations and the effectiveness and comfort of the protective devices.

METHODS, CONDITIONS AND PROCEDURE

Audiometry

Most of the audiometric testing during the experimental period was done with a group audiometer provided by the U.S. Naval Medical Research Laboratory, New London, Connecticut. The instrument was operated by an experienced corpsman from the New London laboratory. It was originally designed by Dr. J. Donald Harris and had recently been calibrated under his direction. With it pure-tone audiograms were obtained on both ears of eight men in less than 20 minutes. The frequencies tested were 512, 1024, 2048, 4096 and 5792*. The reliability of this instrument and of the group method of testing was verified by the observation that men who were tested on this instrument on both experimental days often gave identical readings and only seldom showed differences of as much as 10 db. This is the expected standard of reliability for individual clinical pure-tone audiometry.

The second audiometer employed was a Maico, Model H-1. This is the instrument that had been used to obtain control audiograms on 117 members of the crew in anticipation of the present tests. The earphones of this audiometer, as used for the control audiograms and for seven post-exposure tests on 27 October, were not equipped with standard earphone cushions or headband. The earphones were mounted in "donut-type" cushions in a flight-deck helmet. The large air space under the donut-type cushions materially altered the calibration of the instrument, particularly for frequencies 500, 1000 and 2000 cps. On 27 October standard cushions and headbands were obtained and were used in all tests with this instrument after that date.

The tests with the New London group audiometer were conducted in the ophthalmological examining room adjacent

*The corresponding frequencies on our individual audiometer are 500, 1000, 2000, 4000 and 6000 cps.

to the Aviation Dressing Station. This room is located just below the flight deck. Its ambient noise level was fairly steady at about 70 db. The most troublesome component of the noise was the whine of a ventilating fan with a frequency very near 1000 cps. Testing was suspended during the run-up of aircraft engines on the deck above or other unusual increases in the ambient noise.

The individual audiograms were made in the Dressing Station itself. The ambient noise and particularly the whine of the fan were more troublesome in this room and they probably account for certain systematic discrepancies between the two audiometers at 500, 1000 and 2000 cps. The masking at 500 and 1000 was not only greater but was also more variable than for the higher frequencies. An estimate was made of the usual effective masking levels for the group instrument in terms of the hearing loss readings by noting the lowest values obtained by three or more of the subjects in the group studied on 29 October when they had not been exposed to noise. The average reading was obtained for the individual audiometer with proper cushions and headband by examining all of the audiograms made with this instrument. The cut-off values are given in Table V.

TABLE V

FREQUENCY	512 500	1024 1000	2048 2000	4096 4000	5792 6000
CUT-OFF LEVELS					
GROUP AUDIOMETER	5	5	0	5	0 db
INDIVIDUAL AUDIOMETER (proper cushions)	15	20	10	5	0 db
AVERAGE NORMAL FOR INDIVIDUAL AUDIOMETER with donut cushions	35	45	35	20	10 db

It is only hearing losses greater than the above values that could be measured under the conditions that prevailed, and some of the measured "hearing losses" greater than the above values must also be attributed to temporary increases in the noise background or imperfect seal of the earphone cushions. With the group audiometer there were also occasional erratic "hearing losses" that apparently represent brief lapses of attention of a few of the subjects. The greater interference by masking noise in the outer room where the individual audiometer was located was confirmed in several direct comparisons on the same subjects.

The values given in Table V for the individual audiometer with the donut cushions include not only the masking effects of the ambient noise but also the error of calibration introduced by the large air cavity.

Control Audiograms

The 47 subjects from the USS Coral Sea were selected, as explained below, from a pool of 114 flight deck personnel on whom audiograms had been obtained by the Senior Medical Officer during the previous three weeks while the ship was returning from the Mediterranean. Due to the non-standard earphone cushions, noted above, these control audiograms were not directly comparable with the post-exposure audiograms, but they did serve to identify many significant high-frequency hearing losses that existed prior to the exposures of 27-28 October. A final set of audiograms were taken on 29 October on the 24 men in the USS Coral Sea group who gave the greatest indications of possible temporary hearing losses. These served as control audiograms and formed the chief basis of the estimate of masking levels given in Table V.

Seven of the men who served as subjects for exposure to noise and for audiometric tests were stationed at Naval Air Test Center. Pre-exposure audiograms were obtained on these men on the group audiometer on 26 October. On 28 October these men constituted Group 10 in the placement of personnel in the sound field of the aircraft. After exposure the individual audiometer was used for their audiograms, and therefore the control and the post-exposure audiograms could be compared directly only at 4000 and 6000 cps.

Otological Examination

On 26 October, prior to the distribution of protective devices, each of the 54 subjects for audiometry was examined otologically by Dr. Glorig or Dr. Eldredge. All excess cerumen was removed from the ear canals. About half the subjects showed entirely normal ears. The other half of the subjects showed very minor deviations from normal such as slight thickening of the tympanic membrane, engorgement of the blood vessels around the long process of the malleus and in the pars flaccida, or old well-healed scars on the tympanic membrane. Two subjects had chronic otitis media with loss of tympanic membrane. One of these had an active purulent discharge at the time. Each man except for the two latter subjects was fitted with earplugs (V-51R) and shown how to insert them, and warned to keep them clean.

Protective Equipment

Most of the 54 men who were systematically exposed to the sound fields were also equipped with ear muffs as well as earplugs. Two experimental types of muffs, one designed and manufactured by General Textile Mills and another submitted by the David Clark Company (Models 120 and 124), were incorporated in flight deck helmets. The helmets were individually selected for size when they were distributed to the subjects to ensure proper fit of the ear muffs around the ears of the wearers. A third experimental type of muff (Kindal) was mounted only on a simple spring headband and required no fitting.

The over-the-ear protectors were distributed at random among the 54 subjects. The men who were stationed forward of or opposite the tail pipe, where the over-all sound levels were below 140 db, were instructed to wear over-the-ear protection only, without earplugs, although they were encouraged to wear earplugs during the later launchings that were not part of the noise evaluation study. Nearly all of the remaining 39 men wore both earplugs and ear muffs.

Sound Fields and Positions of Subjects

Nine stations were chosen in the neighborhood of one of the aircraft. They included the areas occupied by personnel during routine launching operations. Five of these stations lay along the midline of the ship midway between the two aircraft. Station 1 was about 20 ft. forward of the line joining the tailpipes of the two aircraft; Station 2 was on this line; Stations 3, 4 and 5 were about 20, 36 and 63 ft. aft of the tailpipes. The four other stations were all in the catwalk where 20 subjects were spaced almost uniformily from a point opposite the tail pipe (Station 6) to 35 ft. aft of the tailpipe (Station 9). The catwalk was 18 to 20 ft. to the right of the axis of the aircraft and roughly parallel to it.

Sound levels were measured at the center of each station while the afterburners of both aircraft were in operation, and in addition a systematic survey was made with respect to spectrum, sound level and the changes with time of the sound fields around each aircraft operating alone. When the afterburner is turned on there is a peak of sound pressure usually 2 or 3 db higher than the above levels that lasts for one or two seconds before the sound settles down to a fairly steady level. The most intense sound field is not at the immediate edge of the blast cone but a little more lateral at an angle of about 45 degrees from the opening of the tailpipe (Stations 4 and 8). In some areas the sound intensity changed rather steeply from point to point within a given station so that men assigned to the same station did not receive precisely the same exposures. The consultants personally explored the entire area occupied by the crew members, both during the preliminary trials on 26 October before the crew members were exposed and during the exposures on 27 and 28 October. The sound conditions at the stations chosen were found to be representative, by subjective judgment, of the entire accessible area around the aircraft.

* TABLE VI

Over-all Sound Levels at the Positions Occupied by Personnel during Operation of Afterburners of both Aircraft Simultaneously

Station		Center of Station Feet from Tailpipe Lateral	Fore or Aft	DB Over-All
1	Midline of Ship	36	20 forward	130
2	" " "	36	opposite	137
3	" " "	36	20 aft	146
4	" " "	36	36 aft	147
5	" " "	36	60-65 aft (close to edge of blast cone)	138
6	Catwalk	18-20	opposite	146
7	"	18-20	11 aft	155
8	"	18-20	20 aft	158
9	"	18-20	35 aft	153

The sound measurements taken from the appendix provided by the Material Laboratory of the New York Naval Shipyard are given to the right of Table VI. Many of the values, corrected for the frequency characteristics of the measuring system, are higher than the tentative values had been. They are particularly high for Stations 6-9, in the catwalk. We do not believe, however, that the personnel were actually subjected to sound pressures quite as high as these figures indicate. In the first place, the measuring microphone was placed actually at the edge of the deck while the personnel stood outboard from it, leaning against the rail of the catwalk. Only their heads were above the level of the deck so that their bodies at least received some protection from the edge of the deck. Secondly, the men at Station 6, who did not wear earplugs, did not any of them complain of pain in their ears. The threshold for pain is well established as at or a little below 140 db and the attenuations provided by ear muffs alone are slight or negligible below about 300 cps. (See BENOX Report). On the other hand we also believe that some personnel at Stations 3 and 4 were exposed to slightly higher levels than prevailed at the microphone. A reasonable estimate is 150 db.

Schedule of Exposures and Audiometric Tests

The "exposure" on 27 October consisted of ten cycles of operation of the afterburners of the two aircraft for 15 seconds at intervals of 45 seconds. The engines continued to operate, but without afterburner and at "idle" power setting, during the intervals. On 28 October the exposure consisted of 15 such cycles. Each group of men was located at the same station and wore the same protection on the two days except for Group 10 who were not exposed on 27 October.

Audiometry was begun on each day within three minutes of the end of the exposure. In general the first man alphabetically in eight of the first nine groups was tested on the group audiometer during the 20 minutes immediately after the exposure. The first man in the ninth group, and on 28 October a member of Group 10 also, were tested on the individual audiometer. During the second 20-minute period the second man alphabetically in each group was tested, and so on. There were a few exceptions, interchanging of times, and slight delays but the testing was completed within two hours of the end of the exposure.

Repeat tests were carried out by individual audiometry during the afternoon of 28 October on six men whose two post-exposure audiograms seemed inconsistent or erratic. A series of control tests was performed by group audiometry during the morning of 29 October on the 24 men who showed the greatest apparent hearing losses, including pre-existing losses.

Selection of Subjects by Psychosomatic Questionnaire

In order to reduce the number of variables in the exposures, each man wore the same protection and each group of men stood at the same station on each day. The sound varied from station to station and it was therefore desirable that each group of men should be as similar to every other group as possible. This was particularly important because it was clearly impractical to rotate each group through all of the stations in the limited exposure time that was available. To match the groups from the neuropsychiatric point of view the Cornell Medical Index (CMI) Health Questionnaire was employed.

The CMI was administered to all 114 men who had had pre-exposure audiograms. The questionnaires were scored immediately in three parts. The first score obtained from each questionnaire consisted of the number of "yes" responses on the portions of the questionnaire having to do with somatic health. The second score consisted of the number of "yes" responses to those questions on the last page of the questionnaire which have to do with the mental health of the individual. The third score consisted of the number of times each individual indicated that he had been knocked unconscious, in reply to Question No. 88: "Were you ever knocked unconscious?" (51 out of 114 men answered "yes" to this question. They were asked to elaborate in a footnote the total number of times and the longest interval of time involved. The number of episodes of unconsciousness ranged from zero to seven; the duration of unconsciousness ranged from five minutes to thirteen and one-half hours.)

With the above three-fold scores available for each of the 114 men, nine groups were chosen containing five men each. A tenth group of six men from Patuxent River Naval Air Test Center was similarly set up. In selecting the subjects for each group, each man was chosen to satisfy one or more of the following criteria:

A) A high neuropsychiatric (NP) score
B) A high somatic score (S)
C) A low NP score and low somatic score
D) Low NP score, low somatic score and zero history of traumatic unconsciousness (U).

The initial scores and criterion code, A, B, C or D, for each subject chosen are shown in Table VII. Following the exposure on the second day the CMI was administered again. The scores are shown in Table VII. In addition the men were asked to write their answers to three questions designed to reveal nonauditory effects of the noise and also the men's practical assessment of the situation.

RESULTS: NONAUDITORY

The exposure of the 54 subjects and also five consultants to the high-intensity sound (up to 150 db) from jet engines for brief periods of time showed no untoward incidents or injuries and no unexpected reactions either physiological, psychological or emotional. For simplicity in exposition the nonauditory results will be described first before the more detailed audiometric findings.

Cooperation of the subjects was wholehearted throughout at all levels. One question asked them after the exposures was "Do you have any suggestions that might improve the situation?" The replies were well-considered and included nearly everything previously thought of by the consultants. They dealt with changes in operational procedure as well as with personal equipment. These replies gave evidence of a serious and mature attitude toward the entire procedure that lends additional value to the other answers, opinions and subjective reports given by the subjects.

Psychosomatic Questionnaire

The data in Table VII show that there is no significant increase in subjective symptoms, either somatic or mental, following the two exposures to the noise. This is true for men both with high and with low initial scores in both categories.

Among the written questions asked of the men after exposure the most important was "Would you be able to carry out your flight deck assignments in this level of noise?" Thirty-five men answered "yes"; ten answered "no." Table VII shows that five of the "no" answers were given by men exposed to levels above 140 db and five by men exposed only to levels of 140 db or below. The table also shows that these ten negative answers are not significantly related either to high scores or to low scores on either the "somatic" or the "mental" series of questions asked in the CMI Health Questionnaire. In designing the experiment the possibility had been considered that "a certain kind of man," identifiable by the Questionnaire, might react unfavorably to the prospect of working in such high noise levels, but no such indication appeared.

The jobs of the men were compared to their scores. With few exceptions the men who had high scores, either psychosomatic or neuropsychiatric, normally worked very close to operating aircraft. However, there were insufficient numbers of men having identical jobs to make detailed comparisons.

Nonauditory Sensations

In reply to the question "How did you feel while in the noise field?" the subjects described a variety of unpleasant nonauditory sensations, sometimes even "painful," in the nose, throat, chest and head. The "pain" seemed to be referred particularly to the nose and sinuses, and was ascribed to the "vibration". The present consultants and several Naval

TABLE VII

Group	Tentative Over-All Sound Level: DB	Name	Protection	"Can you work in this noise?"	Cornell Medical Index BEFORE NP S U	Code	AFTER NP S U	Pre-Existing Hearing Loss: DB 2048	4096	5792
1	130	Brg	C 120	No	26,2,0	B	25, 2,0	5	15	0
								10	15	0
		Cob	K	Yes	5,3,0	D	4, 3,0	5	30	5
								5	20	0
		Ma	C 124	Yes	51,33,1	A	49,29,1	0	5	20
								0	30	40
		Pu	C 120	No	6, 1,1	C	3, 0,1	15	15	0
								10	25	10
		Wr	K	Yes	5, 0,0	C	5, 0,0	0	15	5
								0	25	5
2	137	Ba	K	--	5, 1,0	C		10	5	-5
								10	10	-5
		Dar	GTM	Yes	7, 2,0	D	6, 1,0	0	15	0
								0	10	40
		El	GTM	Yes	40,30,1	A	34,25,1	30	30	35
								30	35	30
		Ho	GTM	Yes	24, 5,1	B	25, 1,3	10	20	40
								20	25	20
		Mas	C 124	Yes	5, 1,0	C	4, 0,0	0	0	0
								0	10	0
		Mi	K + V51-R	--		?		15	30	20
								15	25	10

TABLE VII (CONTINUED)

Group	Tentative Over-All Sound Level: DB	Name	Protection	"Can you work in this noise?	Cornell Medical Index BEFORE NP	S	U	Code	AFTER NP	S	U	Pre-Existing Hearing Loss: DB 2048	4096	5792
3	146	Dav	V51-R	Yes	17	12	1	A	23	11	1	5	10	5
												5	10	10
		Dr	GTM + V51-R	Maybe	6	3	0	D	7	3	0	10	20	0
												5	10	0
		Cr	K + V51-R	Yes	2	1	1	C	3	1	1	0	20	35
												0	5	45
		McD	GTM + V51-R	Yes	22	3	0	B	19	4	0	0	45	30
												5	25	5
		Wi	C120 V51-R	Yes	3	1	0	C	3	1	0	0	15	0
												5	25	0
4	147	Fe	C120 + V51-R	Yes	2	0	1	C	3	0	1	0	5	0
												0	10	5
		Fl	C124 + V51-R	Yes	7	1	0	D	7	1	0	15	35	30
												15	30	15
		Ke	C120 + V51-R	Yes	23	11	1	A	16	4	1	5	25	0
												15	40	15
		Um	GTM + V51-R	Yes	3	0	0	C	3	0	0	0	0	5
												0	10	0
		WA	GTM + V51-R	Yes	20	55	0	B	21	4	0	10	25	15
												5	20	0

TABLE VII (CONTINUED)

Group	Tentative Over-All Sound Level:DB	Name	Protection	"Can you work in this noise?"	Cornell Medical Index BEFORE NP S U	Code	Cornell Medical Index AFTER NP S U	Pre-Existing Hearing Loss:DB 2048	4096	5792
5	138	Cad	-- V51-R	Yes	21, 7, 1	A	14, 4, 1	0 0	15 20	0 15
		Can	K + V51-R	No	19, 2, 0	B	19, 1, 0	5 10	25 25	25 10
		Ch	K + V51-R	Yes	0, 0, 0	C	0, 0, 0	0 0	0 15	0 0
		Fo	GTM + V51-R	Yes	8, 0, 0	D	16, 1, 0	20 15	30 35	5 20
		Sc	GTM + V51-R	Yes	2, 0, 0	D	3, 0, 1	0 0	15 20	5 0
6	146	Cor	K	Yes	25, 0, 1	B	21, 0, 1	5 0	45 15	40 10
		Cu	K	Yes	17,30, 0	A	13,21, 0	5 10	30 20	45 15
		Lo	GTM	Yes	8, 2, 0	D	8, 1, 0	0 0	0 0	0 0
		Ot	GTM	Maybe	5, 0, 0	C	4, 0, 0	0 5	15 15	0 0
		St	GTM	No	4, 1, 0	C	4, 1, 0	5 5	50 50	20 35

TABLE VII (CONTINUED)

Group	Tentative Over-All Sound Level:DB	Name	Protection	"Can you work in this noise?"	Cornell Medical Index BEFORE NP S U	Code	Cornell Medical Index AFTER NP S U	Pre-Existing Hearing Loss:DB 2048	4096	5792
7	155	An	--	No	6, 0, 1	C	5, 0, 1	5	10	0
			V51-R					0	20	5
		Com	C 124 +	Yes	1, 1, 0	C	1, 0, 0	5	15	5
			V51-R					5	15	5
		Hu	GTM +	Yes	19,18, 0	A	17,18, 0	15	60	45
			V51-R					15	25	0
		La	GTM +	Yes	8, 0, 0	D	5, 0, 0	0	5	0
			V51-R					0	15	0
		McK	GTM +	No	23, 4, 0	B	19, 3, 0	5	25	0
			V51-R					10	30	10
8	158	Bo	GTM +	No	4, 0, 1	C	5, 0, 3	15	20	20
			V51-R					15	40	50
		Cam	C 124 +	Yes	20, 2, 1	B	18, 0, 2	0	0	0
			V51-R					0	25	0
		Mar	GTM +	Yes	11, 11, 0	A	5, 4, 0	5	5	0
			V51-R					0	5	0
		Pa	GTM +	Yes	4, 2, 0	C	4, 3, 0	5	5	5
			V51-R					10	0	0
		Gw	GTM	Yes	10, 0, 1		5, 0, 1	5	40	5
			V51-R					5	50	0
		Qu	--	Maybe	4, 2, 0	D	4, 2, 0	10	10	0
			V51-R					0	5	0

TABLE VII (CONTINUED)

Group	Tentative Over-All Sound Level:DB	Name	Protection	"Can you work in this noise?"	Cornell Medical Index BEFORE NP S U	Code	Cornell Medical Index AFTER NP S U	Pre-Existing Hearing Loss:DB 2048	4096	5792
9	153	Brh	K +	No	3, 0, 0	C	4, 0, 0	10	60	70
			V51-R					10	65	60
		Bu	K +	Yes	20, 2, 1	B	19, 2, 0	5	50	35
			V51-R					15	15	0
		Ge	GTM	Yes	3, 2, 0	C	3, 2, 0	0	10	5
			V51-R					5	10	0
		Huf	K +	No	33, 8, 0	A	31, 6, 0	0	10	0
			V51-R					0	0	0
		Sh	GTM	Yes	6, 0, 0	D	5, 0, 0	0	10	10
			V51-R					0	15	10
10	146	Pa	K +	--	5, 0, 1		4, 0, 1	0	15	0
			V51-R					0	15	0
		Ba	--	Yes	10, 0, 0		5, 0, 0	0	5	0
			V51-R					0	5	0
		Ge	--	--				5	25	10
			V51-R					0	10	0
		Mas	--	--	8, 6, 0		5, 6, 0	0	10	-5
			V51-R					5	5	10
		Mat	--	Yes	0, 1, 7		1, 0, 7	0	0	0
			V51-R					5	15	0
		To	GMT +	No	15, 4, 2		10, 1, 2	5	15	10
			V51-R					5	15	10
		Se	--	Yes	10, 0, 0		9, 0, 0	5	10	0
			V51-R					0	10	10

NOTES ON TABLE VII

Protective items are coded as follows:

UTM - United Textile Mills helmet with ear muffs
C 120 - Old model David Clark Co. Inc. helmet
C 124 - New model with ear muffs
Kindal - Ear muff developed by Dr. Kindal
V51-R - Insert-type earplug, Navy equipment

See text for explanation of Cornell Medical Index

NP - neuropsychiatric score
S - somatic score
U - number of times man has been knocked unconscious

Code: A - high NP
B - high S
C - low NP and low S
D - low NP, low S and Zero U

Pre-existing hearing losses are taken from an estimate of the probable "best" audiogram of each man, based on all tests. In each case the losses for the right ear are given first.

Medical officers explored the most intense sound fields personally and they can also testify that these sensations, many of which seem to arise from resonance effects in the sinuses and other parts of the respiratory tract or from rapid movement of air through small openings such as the partly closed lips and from vibration of the lower jaw, are both unpleasant and distracting. Some men experienced the sensation of difficulty in breathing. Tactile (vibratory) sensations in the abdomen were strong in the more intense sound fields. One man complained of nausea. None mentioned any actual pain in the abdomen. All men seemed fully able to maintain the erect posture and none complained of muscular weakness or vertigo, although the combination of actual blast and a feeling of forced movement when the afterburner is ignited is disconcerting when not expected.

It is noteworthy that no pain in the ears or vertigo was reported by any subject. The combined protective devices were evidently adequate in this respect. Three of the consultants, however, explored the more intense sound fields without earplugs and with only the ear muffs. All three felt pain in the ears at least once, particularly with the Kindal ear muff alone.

It must be emphasized that although the subjects had no difficulty standing erect, and although, on the other hand, ten of them expressed the opinion that they would not be able to carry out their routine duties in such noise levels, <u>there were no actual tests of performance in the noise.</u> To evaluate the negative opinions it would be necessary to consider not only what the man's routine duties were but also <u>how</u> he believed the noise would interfere.

<u>Otological Injuries</u>

No subject complained of pain in his ears during or after the exposures. No subject complained of tinnitus or ohter otological symptoms. The only ears that were re-examined after the exposure were the two which had evidence of chronic middle ear infection. This condition had not been made perceptibly worse by the exposure.

RESULTS: AUDITORY

The audiometric tests were included in the present study to measure the temporary hearing losses, if any, produced by exposure to various intensities of the noise of jet aircraft and to distinguish, if possible, among several protective devices in respect to the protection afforded the ear. Actually, although quite incidentally, the study yielded a sample of the auditory acuity of flight deck personnel. This sample gave evidence of cumulative high-tone hearing losses that these men had incurred before the beginning of the present tests.

Limitations from Masking Noise

The most serious difficulty, as anticipated, was masking noise. Most of the audiograms were taken during a period when there were few engine run-ups or launches so that the most serious noises were from the ventilator fan and from the ship's engines. These sounds tended to mask tones of 1000 and 500 cycles per second. Unfortunately it is at just these frequencies that the greatest temporary hearing losses are to be expected on the basis of the known spectrum of the jet engine noise, the known attenuation characteristics of earplugs and ear muffs, and the known relation between temporary hearing loss and the spectrum (at the ear) of the sound that produces it.

With the group audiometer only one subject in the control tests on 29 October reported hearing the 512 cps tone at "normal", i. e. at zero hearing loss on the audiometer. None heard the 1024 tone at "normal." Several, however, heard each tone at the 5 db hearing loss level. We attribute to masking the failures to reach the normal zero level. It is probable that the actual scatter of thresholds from 5 up to 20 db hearing loss represents fluctuations in masking noise from moment to moment and place to place. Perhaps the ear cushions did not always fit tightly.

On the other hand, just about half of the subjects hear the tone at zero hearing loss at 2048 and at 5792 cps. This is the normal expectation. We conclude that masking did not interfere significantly at these frequencies. (There are fewer normal thresholds at 4096 cps than expected, but we shall see that this almost certainly represents real hearing loss at this frequency.)

We conclude that our audiometric tests are valid for small hearing losses at frequencies 2048, 4096 and 5792 but that they could not detect small losses at the lower frequencies.

Reliability of Audiometer Tests

The reliability of the audiometric tests was not investigated systematically by taking repeated controls, nor have the actual data been subjected to elaborate statistical analysis. Most of the subjects on the two post-exposure tests gave thresholds that were identical or within five decibels for the most part. Occasionally there were differences of 10 db and rarely of 15 db or more. This we consider is satisfactory reliability in view of the possibilities of variations in masking noise. Several accidental fluctuations were detected and were corrected by additional individual audiometric tests.

Temporary Hearing Losses

Because of the recognized presence of occasional erratic but spurious high readings on the audiometric tests the following criterion for a "significant temporary hearing loss" was adopted: deviations of at least 10 db from the subjects own post-exposure audiogram (if available) or from the effective masking limits (Table V) must be present at two or more adjacent frequencies. The logic of the last requirement is that the jet engine noise has a broad spectrum and may therefore be expected to produce a temporary hearing loss over at least two octaves. This requirement of loss at two adjacent frequencies eliminates the spurious fluctuations at single frequencies mentioned in the previous section. By this criterion there were no temporary hearing losses of as much as 10 db at frequencies 2000, 4000 and 6000 cycles per second in any of our post-exposure measurements. At frequencies 500 and 1000 cps the results were equivocal. By inspection of audiograms we cannot prove either the presence or the absence of temporary hearing losses up to as much as 25 db. Quite certainly there were none greater than 35 db. This uncertainty is due to the presence of masking noise and to the possibility that it may vary. It must also be remembered that although the hearing tests began within five minutes of the exposure they were not completed, for the last man in each group, until nearly two hours after the exposure.

Some evidence against the presence of any large or systematic amounts of temporary hearing loss is given by the following average hearing losses (Table VIII). Only measurements on the group audiometer are included and the comparison is between the two post-exposure tests, (27 and 28 October) when temporary hearing loss might have been present, and the control tests on 29 October when the masking was the same but when recovery would have occurred from any temporary losses.

TABLE VIII

Average Hearing Loss Readings in Decibels

Frequency cps	Number of Ears Ave.	Control	Post-Exposure	Difference
512	22	13.0	16.5	3.5
1024	22	12.0	14.1	2.1
2048	42	5.8	5.8	0.0
4096	42	19.4	21.9	2.5

These figures show that the differences are small. More elaborate statistical treatment does not seem warranted, particularly in the absence of a more extensive series of control audiograms.

Merits of Protective Devices

Independent information makes it quite certain that considerable temporary hearing losses would have been produced in unprotected ears by the exposures, even though brief, to the levels above 140 db. The measurements do not prove that the ears were protected against all hearing loss, but they do show that the temporary losses did not average more than the values given in the fourth column of Table VIII and may have been much less than this. It is therefore obviously impossible to draw any conclusions as to the relative protection afforded by the different ear muffs. No temporary hearing losses were measured, and we can only conclude that all of the protective devices used were adequate within the delicacy of the test.

Pre-existing Hearing Losses

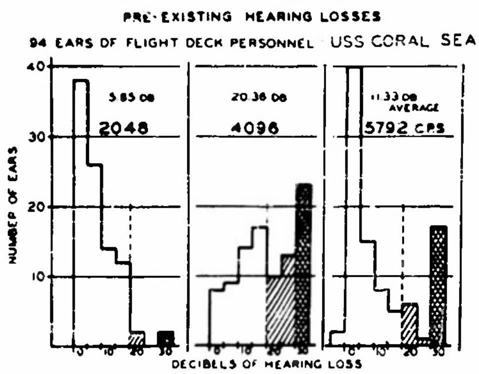
The audiograms taken on 27, 28, 29 October show a much greater average hearing loss at 4096 and also, to a less extent, at 5792 than at 2048 cps. The pre-exposure control audiograms taken prior to 27 October are not comparable because of the masking noise and the non-standard ear cushions described above. The first 20 (alphabetically) that did not show obvious high-tone (4000 and 6000 cps) hearing losses were therefore averaged to obtain a "normal" for this group. (These are the values entered in Table V.) Individual variations from this norm, particularly at 4000 and 6000 cps, are evidence of pre-existing high-tone hearing losses.

All of the significant high-tone hearing losses found in the post-exposure control tests (29 October) were clearly indicated in these pre-exposure controls. It seems clear, therefore, that the experimental exposure of the personnel to noise on 27, 28 October did not of itself produce these permanent high-tone hearing losses. This conclusion is powerfully reinforced by our failure to demonstrate even temporary hearing losses of significant amount in the post-exposure tests. It is universally agreed that a noise strong enought to cause a permanent hearing loss after repeated exposures will cause a still greater temporary hearing loss after each individual exposure. The conclusion follows that the high-tone hearing losses measured in the three hearing tests on 27, 28, 29 October represent pre-existing and presumably permanent hearing losses. Some of these losses, particularly if confined to 4096 cps alone, are presumably the so-called "4000 cycle dip" that is frequently seen in men's audiograms. Some of these dips may be "spontaneous" or "congenital," but they also may have been caused by previous exposure to high-intensity noise incident to the duties of flight deck personnel. Repeated exposure to high-intensity noise is known to cause exactly this type of permanent high-tone hearing loss: the so-called "boilermaker's deafness."

All of the audiograms obtained on 27, 28 and 29 October on the flight deck personnel of the USS Coral Sea (47 men) were examined and the most representative values for the hearing at 2048, 4096 and 5792 cps were estimated for each ear. Only losses that appeared consistently were considered. The averages, and also the corresponding averages obtained at the Naval Air Test Center are as follows:

TABLE IX

	USS Coral Sea (N-94 Ears)	Patuxent River NAS (N-32 Ears)
Frequency	Average Hearing Loss	Average Hearing Loss
2048	5.9 db	3.3 db
4096	20.4 db	2.5 db
5792	11.3 db	1.4 db



The distribution of the individual losses is shown in Fig. 1. There are only four ears out of 94 with losses of 20 db or more at 2048 cps, but there are 46 and 24 with such losses at 4096 and 5792 cps respectively. Even more significant are the large numbers (23 and 17) with losses of 30 db or more at the two highest frequencies.

Three of the four ears with losses of 20 db or more at 2048 cps did not show the typical pattern of "boilermakers deafness" but in each case there was good evidence that a hearing loss, with or without a chronic otological condition, had existed for some time prior to these tests. These four ears also showed losses above and below 2048 cps.

In sharp contrast to the USS Coral Sea group the 32 otologically normal ears tested at the Naval Air Test Center showed no single loss of as much as 20 db at 2048, 4096 or at 5792 cps in the best estimates that could be made for the true normal audiogram for each ear. In fact there were only four losses as large as 15 db, one at 2048 and three at 5792 cps. These men from the Naval Air Test Center were also Navy personnel but have had fewer months of service and much less intimate exposure to the noise of jet aircraft. They form a very satisfactory control group.

Among the flight deck personnel the hearing losses of 30 db or more appear particularly among directors, chockmen, elevator operators, barrier operators and arresting gear chiefs and recorders. No such losses were found in a photographer, tractor driver, fly talker, deck officer or petty officer. Not more than four men in any one category were tested, but it would seem that in general it is the men whose duties bring them close to the jet aircraft in operation who show the significant high-tone hearing losses. The pattern is virtually the same for the less severe losses of 20 and 25 db. This correlation supports the view that the permanent high-tone hearing losses that appear in the flight deck crew but not in the Naval Air Test Center personnel have actually been caused in large measure by the intense noise of aircraft to which the flight deck personnel have been exposed.

DISCUSSION AND RECOMMENDATIONS

The results described in the previous section lead to several practical conclusions as to the effects of certain actual sound fields on personnel and the probable ability of personnel to carry out the present pattern of operations. The results also suggest opinions as to the probable effects of slightly stronger sound fields. These problems will be considered more fully in a separate report that will combine the results of the present study with past experience in related areas and with a recent report ("BENOX," ONR Project NR 144079) of studies on the effects of high intensity sound carried out during the summer of 1953. The conclusions drawn from the present studies are influenced by these other studies. This is quite proper because the observations made on board the USS Coral Sea were necessarily limited in scope and were more in the nature of a practical trial than a fully controlled scientific study.

The tests were planned to expose personnel to a series of bursts of noise a little more severe than would be encountered during a series of actual launching operations. The actual trials were conducted with the aircraft held in position on the deck instead of actually launching and with the afterburners of two planes operating simultaneously. The ear muffs and earplugs that were employed actually prevented any measurable hearing loss either permanent or temporary. Furthermore no nonauditory disabling effects such as vertigo, nausea, muscular weakness, pain in the sinuses, etc. appeared sufficiently to suggest immediate serious difficulties or hazards. It is concluded therefore that <u>with respect to the immediate effects on flight deck personnel, properly equipped with ear protection, the operation of aircraft that do not create sound fields of the usual jet engine spectrum at levels above 150 db over-all at positions to be occupied by personnel is clearly feasible</u>. Furthermore very brief bursts of noise a few decibels above 150 db, like the initial peak when an afterburner is turned on, are permissible. On the other hand, the conclusion that no immediate injurious effects are produced by jet engine noise at 150 db must for the present be restricted to a series of exposures of 15 seconds each and totaling less than 5 minutes exposure to such intensity in an entire day.

<u>Ear Protection</u>

The sound field of 150 db proved tolerable to personnel who were wearing V51-R earplugs alone (in a few cases) as well as when combined with some form of ear muff. On the basis of other information it is very probable that serious hearing losses and perhaps other injury would have been produced if no protection had been worn in such a sound field. The specific conclusions that can be drawn from the present tests are:

1. Each of the three ear muffs alone prevented pain and any detectable immediate hearing loss from the exposures to sound pressure levels of less than 140 decibels.

2. The V51-R plugs alone, or in combination with any of the three ear muffs, prevented pain and any detectable immediate hearing loss from the exposures to levels as high as 150 decibels.

3. It was not possible to measure differences in the protection afforded by the various ear muffs.

4. Ear muffs alone did not entirely prevent pain in the ears at levels at or near 150 db. This, taken in connection with independent evidence presented in the BENOX report, indicates a sound level under the ear muff, probably due chiefly to frequencies between 300 and 1000 cycles per second, of 135 to 140 db. Such a sound level is potentially injurious to the ear. The muffs alone therefore cannot be considered adequate protection for long or repeated exposures to such high sound levels. For levels below 140 db, however, either earplugs alone or properly designed ear muffs alone should provide adequate protection for carrier operations.

It must be noted that in the present trials both the earplugs and the helmets that carried the ear muffs were fitted to the subjects and the subjects were indoctrinated in their use. In all recommendations for the use of ear protectors it is assumed that adequate fitting and indoctrination in their use will be provided.

The choice of a particular ear protector for use in any given operational situation involves a compromise among many considerations of acoustic effectiveness, dependability, comfort, cleanliness, convenience and so on. Specific recommendations for the flight deck of aircraft carriers, based on these considerations and on the results of the present tests, are presented elsewhere in the main body of this report.

Nonauditory Effects

Some nonauditory effects such as pain in the ears and certain disturbances of the sense of equilibrium are produced by sound that enters the ear canal. These effects are, of course, prevented or reduced by the same ear protectors that prevent injury to hearing. Other nonauditory effects are produced by the direct action of sound on other organs of the body. They are not prevented by ear protectors and in very intense sound fields probably cannot be effectively prevented by any measures short of complete enclosure of the man or removing him from the sound field. These effects include direct injury, pain, nausea, feelings of muscular weakness or incoordination, and general feelings of discomfort, anxiety, confusion, fatigue and aversion. These effects cannot be predicted in detail in advance. It is therefore good to know that no serious effects of this kind or evidence of immediate injury of any sort appeared in any of our subjects. It would not be proper, however, to discount completely the adverse reports of the subjects and the experiences of the consultants concerning the very strong and unpleasant nonauditory sensations. Our best judgment is that pain or nausea or unsteadiness of eye or hand are likely to hamper the performance of routine duties if personnel are exposed to noise of this character and spectrum at levels much above 150 db, even with the best possible protection of the ears. A few more decibels will probably be tolerable, but it should not be assumed, in the absence of actual experience, that personnel will be able to perform present duties in or even tolerate without injury repeated exposures, even brief exposures, to over-all sound levels above 160 db.

About twenty percent of the subjects expressed the opinion that they could not carry out their routine duties in the noise to which they were exposed, even though they wore ear protection. The important point here is that although some of the subjects think the limit has already been reached <u>no actual tests or trials of ability to perform such duties were attempted</u>. It will be important to observe actual performance of personnel closely when aircraft of the type tested are flown from carriers as routine. Perhaps familiarity with intense noise will soon lead to a relative indifference to it as it so often has in the past. Indoctrination seems very effective for the initial fear and "sense of impending doom" that is so common in one's first exposure to the sound of a jet engine at really close range. Indoctrination may not be so effective against the very real and strong non-auditory sensations or against the development of chronic fatigue. Here again close observation will be necessary.

<u>Long-term Effects of Intense Sound</u>

The present study was confined to a single series of exposures on each of two successive days. It is obviously impossible to draw conclusions from such brief experience as to possible cumulative long-term injurious effects, either on the ears or perhaps directly on the nervous system, as suggested by certain findings in the BENOX report. There it was found, for example, that the performance of five out of ten mechanics, who had serviced jet aircraft for two years or more, on a series of tests suggested the possibility of injury to certain parts of the nervous system. Neurosis was one of the possible alternative explanations. Noise may have been responsible. The only way to detect and safeguard against such possibilities will be to monitor carefully the personnel exposed to noise over long periods with periodic neurological examinations and appropriate tests of psychosomatic functions. The initiation of such monitoring is recommended.

The present audiometric tests do show quite clearly that high-tone hearing loss is more prevalent among the flight deck personnel of the USS Coral Sea than among the personnel tested at the Naval Air Test Center. It is also more prevalent than among an average sample of young men of this age group (18 to 29 years) in the general population. The character of the hearing loss and its incidence is more like that encountered in certain industries where workers are habitually exposed to high levels of noise without adequate ear protection. ("The Relations of Hearing Loss to Industrial Noise," American Standards Association, 1953.) It seems reasonable to attribute the prevalence of high-tone hearing loss among the flight deck crew to their previous exposure to noise. None of the losses observed are at all incapacitating but they do show that with present aircraft an appreciable amount of cumulative permanent hearing loss is already being produced. The men with these losses are still fully able to hear and understand ordinary speech but in a few of them the hearing loss is about to encroach significantly on the so-called "speech frequencies" of hearing.

It would seem wise from the medical point of view, when such severe high-tone hearing losses are recognized, to remove the men in question from intense noise before the injury to hearing becomes severe enough to constitute a practical handicap. It is believed that the consistent use of ear muffs and plugs will reduce and perhaps entirely prevent this type of hearing loss.

It is recommended that both earplugs and ear muffs be used in the most noisy situations. This double protection is more effective acoustically than either protector used alone and it gives greater assurance that at least one or the other will be effective in case either the plug or the ear muff in a helmet does not fit perfectly. Even so, however, in very intense sound fields such as we must expect in the future, there may be occasional failures and some hearing losses must be anticipated. It will be the responsibility of the medical officer to detect these losses. It is strongly recommended, therefore, that routine audiometry be established.

The present studies show that it is possible to make fairly satisfactory tests of hearing for high tones (where permanent hearing losses usually occur first) on board a carrier while it is underway. It was also found, however, that noise conditions prevented really adequate tests for the lower tones. A moderate amount of sound treatment and a slight modification of the ventilating system would have made the actual situation acceptable even if not ideal. If audiometric monitoring is to be established, either ashore or afloat, proper facilities for it must be provided.

A long-term monitoring program is recommended not only for audiometry but also to include associated otological examinations as well as the neurological and psychosomatic tests already mentioned. On the basis of this monitoring more frequent rotation of personnel whose duties require frequent exposures to noise at levels above 140 db should be made on the advice of the ship's medical officer when audiometric or psychosomatic indications appear. Some men are likely to prove more susceptible to such effects than others.

A long-term research program, to supplement the shipboard observations, should be established to deal with questions of gradual deterioration of performance or of auditory acuity.